

OmegaWINGS: OmegaCAM@VST observations of WINGS galaxy clusters[★]

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Received xxx; accepted xxx

ABSTRACT

Context. Wide-field observations targeting galaxy clusters at low redshift are complementary to field surveys and provide the local benchmark for detailed studies of the most massive haloes in the local Universe. The Wide-field Nearby Galaxy-cluster Survey (WINGS) is a wide-field multi-wavelength survey of X-ray selected clusters at $z=0.04-0.07$. The original $34' \times 34'$ WINGS field-of-view has now been extended to cover a 1 deg^2 field with both photometry and spectroscopy.

Aims. In this paper we present the Johnson B and V -band OmegaCAM/VST observations of 46 WINGS clusters, together with the data reduction, data quality and SExtractor photometric catalogs.

Methods. The data reduction was carried out with a modified version of the ESO-MVM (a.k.a. "ALAMBIC") reduction package, adding a cross-talk correction, the gain harmonisation and a control procedure for problematic CCDs. The stray-light component has been corrected by employing our own observations of populated stellar fields.

Results. With a median seeing of $1''$ in both bands, our 25-minutes exposures in each band typically reach the 50% completeness level at $V = 23.1$ mag. The quality of the astrometric and photometric accuracy has been verified by comparison with the 2MASS as well as with SDSS astrometry, and SDSS and previous WINGS imaging. Star/galaxy separation and sky-subtraction procedure have been tested comparing with previous WINGS data.

Conclusions. The SExtractor photometric catalogues are publicly available at the CDS, and will be included in the next release of the WINGS database on the VO together with the OmegaCAM reduced images. These data form the basis for a large ongoing spectroscopic campaign with AAOmega/AAT and is being employed for a variety of studies.

Key words. Methods: observational – Catalogs – Galaxies: clusters: general – Galaxies: photometry – Galaxies: fundamental parameters

1. Introduction

Galaxy clusters, the most massive collapsed structures in the Universe, play an important role for both cosmology and galaxy evolution studies. They are the tail of a continuum distribution of halo masses, and the most extreme environments where galaxy formation has proceeded at an accelerated rate compared to the rest of the Universe. Clusters have been a testbed for studies of galaxy formation and evolution, uncovering trends that several years later have been found also in the field (Butcher & Oemler 1978; Couch & Sharples 1987; Dressler et al. 1997). They are a repository for galaxies that have been shaped in lower halo-mass environments (Wilman et al. 2009), but also the sites where essentially all environmental effects are thought to take place, from strangulation to ram pressure stripping, and even mergers (De

Lucia et al. 2010). As peaks in the matter distribution, they host those galaxies that have formed first and in the most extreme primordial conditions, and at the same time where the hierarchical growth is most evident, like brightest cluster galaxies. There is no better place than rich clusters in the low- z universe to find and study the descendants of the most massive galaxies observed at high- z (Poggianti et al. 2013).

The Wide-field Nearby Galaxy-cluster Survey (WINGS) is a wide-field and multiwavelength survey of 76 galaxy clusters in the local Universe (Fasano et al. 2006). The sample consists of all clusters at $0.04 < z < 0.07$ in both hemispheres at Galactic latitude $|b| \geq 20$ selected from the ROSAT X-ray-Brightest Abell-type Cluster Sample, the Brightest Cluster Sample and its extension (Ebeling et al. 1996, 1998, 2000).

The original WINGS survey is based on B and V imaging for the 76 clusters over a $34' \times 34'$ field-of-view (FOV) taken with the Wide Field Cameras on the INT and the 2.2MPG/ESO telescopes (Varela et al. 2009). J - and K -band Wide Field Camera

[★] Based on observations made with VST at ESO Paranal Observatory under program ID 88.A-4005, 089.A-0023, 090.A-0074, 091.A-0059, and 093.A-0041.

imaging at UKIRT (Valentinuzzi et al. 2009) and *U*-band with the INT, LBT and BOK telescopes (Omizzolo et al. 2014) were secured for a subset of clusters. Spectroscopy was obtained over the $34' \times 34'$ FOV with 2dF/AAT (~ 4000 usable spectra) and WYFFOS/WHT (~ 2500 spectra) (Cava et al. 2009). These data allowed us to derive galaxy morphologies (Fasano et al. 2012), surface photometry and sizes (D’Onofrio et al. 2014), stellar masses, star formation histories, and spectral types (Fritz et al. 2011, 2014; Vulcani et al. 2011), as well as characterise the cluster substructure and dynamics (Ramella et al. 2007, Cava et al. submitted), and conduct a number of studies on galaxy properties and evolution (a full publication list can be found at the WINGS website¹). The WINGS data and data products are publicly available through the Virtual Observatory (VO), as explained in Moretti et al. (2014).

The WINGS optical images, together with the photometry and source classification, were used to calibrate the photometry presented in this paper and for other purposes, as described in the following sections.

The WINGS dataset is unique, as none of the other low-*z* surveys investigate a large sample of clusters and cluster galaxies in such detail. GAMA offers an exquisite sampling down to low-mass haloes, but it lacks a large number of massive clusters at redshifts comparable to WINGS (Robotham et al. 2011). The SDSS (York et al. 2000) provides large cluster catalogues, but has a much lower imaging quality (for seeing, depth, pixel scale, see below), and is 1.5 magnitudes shallower than WINGS spectroscopy, yielding a smaller dynamic range of galaxy magnitudes and masses at the WINGS redshifts.

The main limitation of the original WINGS data is that they cover only the cluster cores: the maximum clustercentric distance reached in (almost) all clusters by the INT+2.2m imaging is only 0.6 times the virial radius. Crucially, what was missing is the coverage out to at least the virial radius and into the outer regions. This would be of primary importance, as it would link clusters with the surrounding populations and the field.

Clusters accrete individual galaxies and larger subclumps from their outskirts. The outer regions of clusters are the transition regions between the cores, with their dense and hot intra-cluster medium, and the filaments (and/or groups) feeding the cluster, at the point where galaxies are subject to a dramatic change of environment. Indeed, observations have proved that the cluster outskirts are essential to understand galaxy transformations (Lewis et al. 2002; Pimblet et al. 2002; Treu et al. 2003; Moran et al. 2007). Moreover, the projected clustercentric radius of galaxies statistically retains memory of the epoch when the galaxy first became part of a massive structure and became a satellite (Smith et al. 2012; De Lucia et al. 2012). Cosmological hydrodynamical simulations predict a depletion of both hot and cold gas and a decline in the star-forming fraction of galaxies as far out as 5 cluster virial radii (Bahé et al. 2013). With the exception of a few single clusters and superclusters (Merluzzi et al. 2010, 2015; Mahajan et al. 2011; Smith et al. 2012; Haines et al. 2011, e.g.), this very important transition region between clusters and the surrounding field remains largely unexplored.

With the aim to cover the virial region and extend out into the infall region, we have obtained GTO OmegaCAM/VST imaging in the *u*, *B* and *V* bands over $1 \times 1 \text{ deg}^2$ for 45 fields covering 46 WINGS clusters. A large spectroscopic campaign to follow up the clusters observed with OmegaCAM is ongoing with AAOmega/AAT (Moretti et al. in prep.).

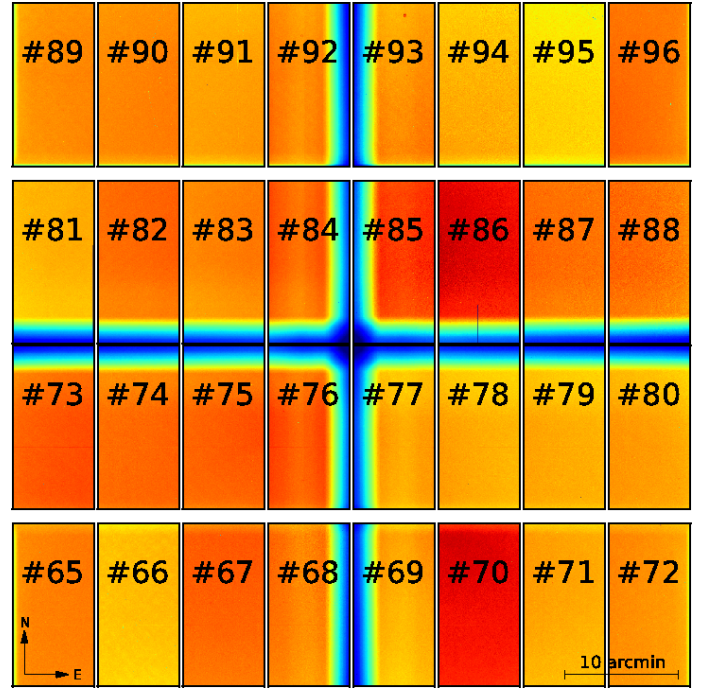


Fig. 1. Layout of the OmegaCAM CCD mosaic. The labels indicate the ESO ID of each chip. The image is a *V*-band raw flat field image.

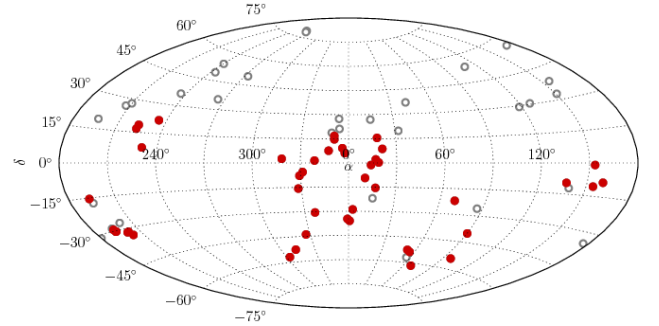


Fig. 2. OmegaWINGS target clusters are shown as filled circles, all WINGS clusters are shown as open circles.

This imaging+spectroscopic dataset is from now on named OmegaWINGS.

This paper presents the OmegaCAM/VST *B* and *V* imaging, the observations (Sect. 2), data reduction (Sect. 3), the release of photometric catalogs (Sect. 4) and data quality (Sect. 5). The *u*-band campaign is still ongoing and will be presented in a subsequent paper.

In the following, we use $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_m = 0.3$, $\Omega_{\text{lambda}} = 0.7$.

2. Observations

The VLT Survey Telescope (VST, Capaccioli & Schipani 2011) is a 2.6-m wide field optical telescope placed at Cerro Paranal, Chile. The telescope is equipped with OmegaCAM (Kuijken 2011), a camera that samples the 1 deg^2 VST unvignetted field of view with a mosaic of 32 $4\text{k} \times 2\text{k}$ CCDs at $0''.21/\text{pix}$. The layout of the OmegaCAM mosaic is shown in Fig. 1; the ESO identification name is superimposed to each CCD.

¹ <http://web.oapd.inaf.it/wings>

OmegaWINGS target clusters were randomly selected from the 57 WINGS clusters that can be observed from VST ($\delta < 20^\circ$). We obtained service-mode *B* and *V*-band imaging for 46 of them with 45 OmegaCAM pointings. Two WINGS clusters –A3528a and A3528b– were observed with a single VST pointing; hereafter this will be referred to as A3528. The position of the target clusters observed by the OmegaWINGS survey are shown in Fig. 2. The choice of *B* *V* filters was taken for consistency with the original WINGS survey, despite the problems related with the segmentation of OmegaCAM Johnson’s filters that are discussed at the end of this section.

Observations started in October 2011 and were concluded in September 2013. The first observations were carried out during ESO period P88 with the OmegaCAM *STARE-mode*, splitting the total exposure time in $3 \times 480s$ observations with no offsets. We adopted this observing mode to obtain a constant signal to noise ratio across the field of view, as in the original WINGS survey. Starting from period P89 we optimised our observing strategy, taking $5 \times 300s$ exposures in *DITHER-mode*, with $25''$ and $85''$ offsets in horizontal and vertical direction, respectively. This observing strategy offers two major advantages: it allows to dither out the gaps between the CCDs and to estimate the contribution of the background light (see next section for details). The log of our observations is summarised in Table 1.

On average, observing conditions were better in *V*-band than in *B*-band. We measured the seeing on each OmegaWINGS image as the mean value of the FWHM of stars profiles. The values are listed in Table 1 and shown in Fig. 3. The seeing is lower than $1''.3$ in 80% of *B*-band images, and lower than $1''.2$ in 80% of *V*-band ones. The median values of seeing are $1''.0$ in both *B*- and *V*-band.

Since OmegaCAM *B* and *V* filters are segmented and composed by 4 quadrants, the interface of the quadrants casts a slight shadow in the form of a cross onto the image plane. This central vignetting cross is $\sim 310''$ wide in both directions. Figure 1 shows a raw flat-field image in the *V*-band, where the vignetting is clearly visible. To remove it from the final stacked images, the OmegaCAM User Manual² suggests a dithering pattern with steps that should be $310''$ in both *X* and *Y* direction. Such wide steps would reduce the field of view covered by 5 exposures. Considering that the central region of each target cluster is covered by WINGS data, we decided to use smaller dithering steps. However, in this way the vignetting cross can not be entirely removed, and our final images have a vertical stripe $\sim 3'$ wide that is strongly affected by vignetting and that was therefore masked out. The horizontal component of the vignetting cross was instead perfectly removed.

3. Data reduction

Image reduction and calibration are mainly based on ESO-MVM –also known as ALAMBIC– reduction package. This is a multi-instrument reduction tool originally developed for the ESO/EIS survey (Mignano et al. 2007). It has been extensively used also in the production of ESO Advanced Data Products, see for instance the 30 Doradus/WFI Data Release³, or the GOODS/ISAAC Final Data Release (Retzlaff et al. 2010). The detailed description of the package and the documentation of the algorithm structure implemented in ESO/MVM are given in Vandame (2004). This section presents a summary of the main reduction

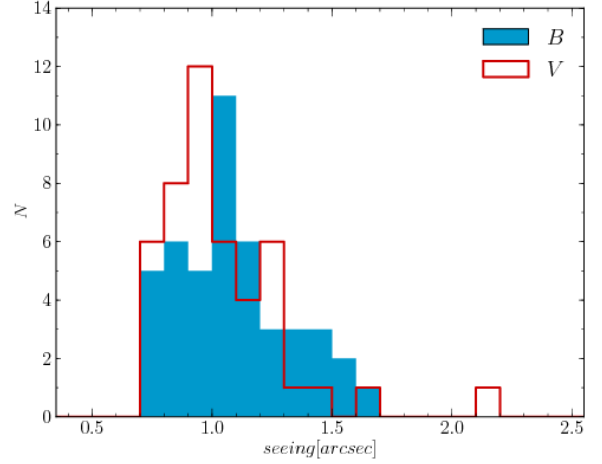


Fig. 3. Mean seeing measured on stacked OmegaWINGS *B*- and *V*-band images

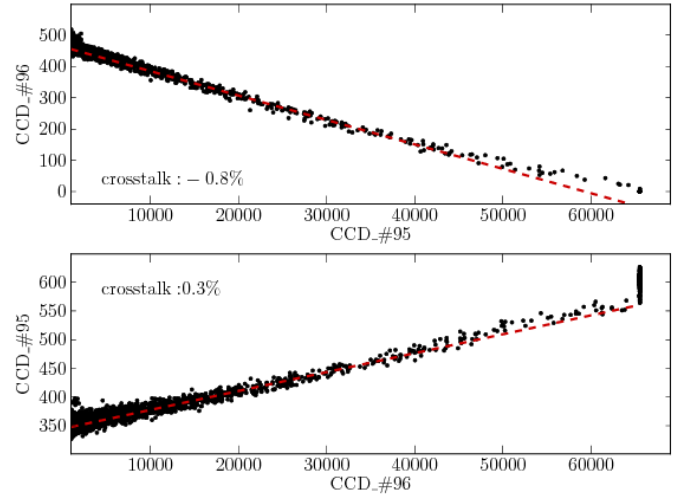


Fig. 4. Cross-talk effect between CCDs #95 and #96. Each point is the count in one pixel in the raw frame of the *receiver* CDD as a function of the count in the same pixel in the *emitter*. There is a positive cross-talk from #96 to #95 ($\sim 0.3\%$) and a negative one from #95 to #96 ($\sim -0.8\%$). Only data-points corresponding to more than 2500 ADUs in the *emitter* has been plotted.

steps and our add-ons to the original pipeline. The latest version of the ALAMBIC code and User Manual can be downloaded at the ESO webpage⁴. Here we used a modified version of the code (kindly provided by H. Bouy and B. Vandame, see Bouy et al. 2015) that has been partially rewritten to take advantages of the most recent hardware and recent Linux libraries. There are configuration files for many optical and near-infrared ESO instruments, but OmegaCAM is not officially supported so far. We therefore created a new configuration file for OmegaCAM, using the instrument description given in the VST user manual.

The following subsections will describe the main reduction steps. The only steps for which we had to develop integrations to ALAMBIC are: the cross-talk correction, the gain-harmonisation and the control procedure to check the quality of CCD #82.

² <http://www.eso.org/sci/facilities/paranal/instruments/omegacam/doc.html>

³ http://archive.eso.org/archive/adp/ADP/30_Doradus/

⁴ <http://archive.eso.org/cms/eso-data/data-packages/eso-mvm-software-package.html>

Table 1. Observation log. Columns 3 and 5 are seeing in B and V measured as the average FWHM of stars in B - and V -band final stacked images. The last column lists the reference astrometric catalogue.

cluster	DATEOBS _B	σ_B	DATEOBS _V	σ_V	src
A85	2013-09-03	0'97	2013-08-03	1'00	SDSS
A119	2011-12-17	1'03	2011-10-23	0'74	SDSS
A147	2013-07-15	0'78	2013-08-05	0'83	SDSS
A151	2012-11-17	0'85	2012-11-04	0'75	2MASS
A160	2011-10-21	0'79	2011-10-21	0'99	SDSS
A168	2013-07-18	1'17	2013-08-03	1'23	SDSS
A193	2011-10-21	0'78	2011-10-21	1'01	SDSS
A500	2011-11-28	1'26	2011-12-02	1'28	2MASS
A754	2011-11-30	0'76	2011-11-22	0'95	2MASS
A957x	2012-03-26	1'05	2011-11-23	1'02	SDSS
A970	2011-12-23	1'64	2011-11-24	1'25	2MASS
A1069	2013-04-13	1'31	2013-05-07	0'87	2MASS
A1631a	2013-03-22	1'16	2013-02-10	0'98	2MASS
A1983	2012-05-18	1'05	2012-03-31	1'23	SDSS
A1991	2013-04-15	0'86	2013-04-14	0'84	SDSS
A2107	2013-04-08	1'03	2013-04-10	1'01	SDSS
A2382	2012-07-20	1'03	2012-06-26	2'12	2MASS
A2399	2012-06-16	0'84	2012-05-29	1'24	SDSS
A2415	2012-07-26	1'49	2012-07-22	0'82	SDSS
A2457	2012-06-16	1'08	2012-07-15	1'13	SDSS
A2589	2013-07-16	1'22	2013-07-13	0'96	SDSS
A2593	2012-10-08	1'41	2012-10-08	1'01	SDSS
A2657	2013-07-17	0'78	2013-07-11	0'77	SDSS
A2665	2013-07-12	0'96	2013-07-12	0'96	SDSS
A2717	2013-08-01	1'57	2013-06-11	1'22	2MASS
A2734	2013-06-20	1'13	2013-07-07	1'06	2MASS
A3128	2011-12-20	1'03	2011-12-18	0'77	2MASS
A3158	2011-12-18	0'95	2011-12-20	0'93	2MASS
A3266	2012-10-15	1'53	2012-10-15	1'10	2MASS
A3376	2013-01-04	1'01	2012-11-17	1'32	2MASS
A3395	2013-03-05	0'89	2013-03-02	1'11	2MASS
A3528	2013-06-02	1'43	2013-06-05	1'11	2MASS
A3530	2013-06-03	0'95	2013-06-06	0'86	2MASS
A3532	2013-06-03	0'91	2013-06-07	0'77	2MASS
A3556	2012-06-17	1'21	2012-05-24	1'44	2MASS
A3558	2013-06-11	0'85	2013-06-28	0'76	2MASS
A3560	2012-06-18	0'89	2012-05-24	1'68	2MASS
A3667	2013-04-13	1'38	2013-05-14	0'95	2MASS
A3716	2013-05-20	1'13	2013-05-20	0'93	2MASS
A3809	2012-07-22	1'12	2012-04-18	0'99	2MASS
A3880	2013-06-11	1'31	2013-06-20	0'92	2MASS
A4059	2013-08-04	1'05	2013-07-03	0'91	2MASS
IIZW108	2013-06-06	1'04	2013-06-06	0'86	SDSS
MKW3s	2012-04-20	1'14	2012-04-19	0'83	SDSS
Z8852	2012-11-10	1'02	2012-10-12	0'83	SDSS

We will call Data Block (DB) the complete set of data taken in each photometric band for a single pointing. A DB consists of 5 science, 5 twilight flat-field and 10 bias frames. Each DB has been reduced independently. This may slightly increase the computational time, because some targets have been observed during the same night and therefore it would have been possible to compute the master bias and flat-field frames only once. However, we prefer to reduce each DB independently because in this way the implementation of the reduction pipeline is much easier and linear. The calibration stacking process is not very time consuming, therefore our choice has a negligible influence on the overall computational efficiency of the reduction process. A typical reduction run for a DB takes about 40 minutes on a Intel i7 3.4GHz computer with 16 Gb of RAM.

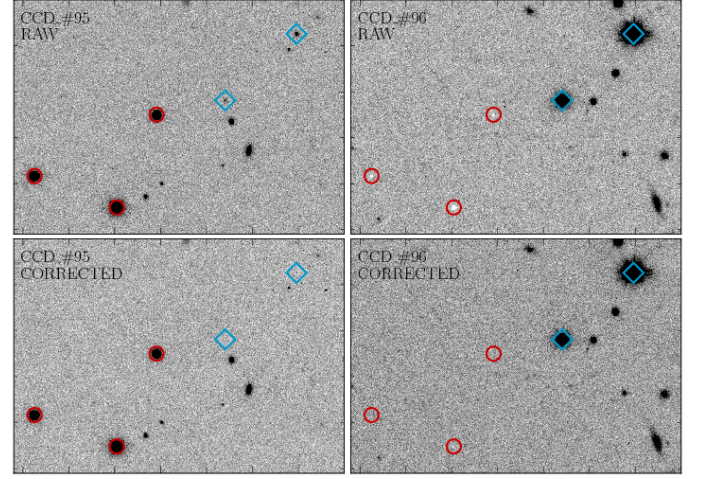


Fig. 5. Cross-talk effect between CCDs #95 and #96. The top panels show how bright sources in CCD #96 produce positive signal on CCD #95, while bright sources in CCD #95 generate “holes” on CCD #96. The corrected images are shown in the bottom panels. Circles and diamonds mark the position of bright sources on CCDs #95 and #96, respectively. Fake sources are removed from the image in the lower-left panel, as well as holes from the lower-right one.

3.1. Data organisation

First of all the multi-extension raw image files are splitted, resulting in 32 single-extension files, corresponding to the 32 OmegaCAM detectors. Images are then classified and grouped together using the information stored in the file headers. ALAM-BIC creates lists of images corresponding to consecutive observations of the same field taken with the same filter, called *observation blocks*. These are used to produce the *calibration blocks*, i.e. lists used to create the calibration images –bias, flats, illumination maps– and the *reduction blocks*, i.e. lists of science observations of each scientific target with the same filter.

3.2. Cross-talk

According to the OmegaCAM User Manual, four detectors (CCDs #93-96, see Fig. 1) suffer electronic cross-talk. The strongest effect, of the order of a few percents, is between CCDs #95 and #96, while it is much lower for all the other CCDs. After a few tests we confirmed the cross-talk for CCDs #95 and #96 and we found that it is negligible in all other cases. The cross talk has been estimated by cross-correlating the signal registered on the same pixel in each pair of CCDs. As an example, Fig. 4 shows the effect in a raw image of one of our science frames. The mean background level for this image is ~ 480 ADUs in CCD #96 and ~ 350 ADUs in CCD #95. When a bright source increases the signal in CCD #96, a signal above the background is registered in CCD #95 (see lowest panel in Fig. 4); the difference between the registered signal and the average background in one detector is proportional to the signal in the other one. Figure 4 shows deviations from the linear relation when the signal is above ~ 50000 ADUs. This is mainly due to non-linearity of the detectors. This non-linearity can be safely ignored, since it affects only a few pixels in each image. We also note that the cross-talk effect of saturated stars in CCD #95 inversely saturates CCD #96 at 0 ADU. To avoid this problem, on September 12th 2012 the bias level of CCD #96 was increased to 650 ADU.

Since ALAMBIC does not include any cross-talk analysis, we developed a fast and easy procedure to calculate and correct for cross-talk. We assumed that the *observed* image is equal to

$$S_r = I_r + \alpha_r^e \cdot S^e \quad (1)$$

where S_r and I_r are the observed and the *real* –i.e. if no cross-talk were present– signal in the receiver, and S^e is the observed image in the emitter detector. α_r^e is the cross-talk coefficient between the receiver and the emitter CCDs. The coefficient has been obtained by fitting a linear relations to the data-points in Fig. 4. In all our images the coefficients for CCDs #95 and #96 are very similar, $\alpha_{95}^{96} \simeq -0.8\%$ and $\alpha_{95}^{95} \simeq 0.3\%$. These values are then used to correct the images, inverting eq. 1. Figure 5 shows the very good results obtained with our procedure.

3.3. Stacking of calibration frames

During this phase of the reduction process, all calibration images of a given science reduction block are stacked together and the corresponding master bias and twilight flat images are produced. During this step, a bad-pixel detection procedure is applied and weight maps for flat field images are computed. Details about the algorithm are given in the ALAMBIC User Manual.

3.4. Gain harmonisation

The electronic converters of each detector are different, and each CCD may have a different efficiency. Therefore, each detector has its own effective gain and, as a consequence, its own photometric zero-point. The chip-to-chip gain variation quoted in the OmegaCAM User Manual is of the order of 10%, resulting in a chip-to-chip zero-point scatter of ~ 0.1 mag. The procedure adopted by ALAMBIC to correct for this is to apply a multiplicative calibration constant to the master flats. The calibration is based on the analysis of a scientific image. The chip background is computed for each of the four borders of each chip in a narrow stripe. Then the chip-to-chip gain variations are calculated by comparing the values of each pair of adjacent stripes on different chips. As an example, in the case of a camera with 4×2 CCDs –as the WFI@ESO2.2m instrument–, the total number of equations, one for each pair of stripes, is 10, and the unknown parameters are the seven unknown flux-scales (this is a relative calibration). In this way it is possible to obtain a robust calibration even if the sky-background is not constant and presents, for example, some gradients.

The central vignetting cross does not allow to use the standard ALAMBIC procedure for gain harmonisation. Given the high flux loss in a wide cross-shaped region at the centre of the field of view of the camera it is not possible to easily connect the background values of adjacent regions of different CCDs affected by the central vignetting. We therefore developed a variation of the original ALAMBIC procedure optimised for our specific OmegaCAM observations. First of all we note that the background level in our raw images does not show any significant gradient within each single detector. We can therefore assume a constant sky background across the whole FoV. We took one of the detectors as a reference and scaled the master flat field image of the other 31 according to the ratio of the mean background values for each CCD on a science image. We recall that the reduction process is done independently for each DB, and hence also this process is repeated for each OmegaWINGS field in each filter. This procedure can be used since all our science images are not extremely crowded. The background estimation,

and consequently the gain-harmonisation, would not have been possible otherwise, as in the case of observations of e.g. giant nearby galaxies with sizes of the order of one OmegaCAM CCD, or observations of the central regions of galactic globular clusters, nearby resolved galaxies or other crowded stellar fields. In such cases it would be difficult –if not impossible– to estimate the sky background in each detector.

When the re-scaled master flat-field images are used to calibrate scientific images, the chip-to-chip gain variation is corrected and the resulting calibrated images therefore have a uniform background value. The quality of this procedure will be discussed in the following sections, in the context of the discussion of the overall photometric performances of our reduction pipeline.

To conclude this section, we add an important note about CCD #82 (its location on OmegaCAM mosaic is shown in Fig. 1). The OmegaCAM User Manual report day-to-day gain variations of a few percent, since the start of OmegaCAM operations. We note that for many observations there are serious problems on CCD #82. The background value is not constant, showing strong discontinuities in the form of horizontal stripes with different background values. The position and the extension of these stripes are in general different from one image to the other, even for consecutive observations within the same DB. For this reason, we decided to discard all CCD #82 data when one scientific image in the DB is affected by this problem. We implemented in the pipeline a simple script to test whether CCD #82 background is stable. If this is not the case, all CCD's pixels are assigned a null weight. On June 2nd 2012 ESO changed the video board connected to CCD #82 to fix this issue.

3.5. Illumination correction

A well known problem affecting in particular wide field cameras is the sky-concentration, i.e. stray-light component centrally concentrated. This mostly affects observations with extremely bright background. In particular, flat-field frames are the most exposed to this effect. The net result, when flat-field exposures are applied without any correction, is an erroneous apparent trend of photometric zero point with distance from the centre of the camera field of view.

A common technique used to correct for this effect is to compute an illumination map to be applied to the flat-field frames, in order to obtain *photometrically flat* reduced science frames. ALAMBIC implements an algorithm to compute and apply the illumination map, which is based on a sequence of dithered observations of the same stellar field. Basically, these images are reduced using the *normal* flat field and photometric catalogs are extracted for each image. Since each star will be placed at a different position in each image, it is possible to map the zero-point variations as a function of the position on the focal plane. This is done using a least square estimator with rejection approximating the illumination map with a 2D polynomial function. This map is finally multiplied by the flat-field frame. A detailed description of the algorithms is given in Vandame (2002).

To compute the illumination map we observed a well populated stellar field, namely the Landolt SA107. We obtained 5 images in both the *B*– and *V*–bands, using a dithering path wide enough to obtain observations of the same stars in different positions in the OmegaCAM focal plane. An outline of the dithering pattern is shown in Fig. 6. These observations were used to compute the illumination map, using a 4th order polynomial function. This illumination-correction map has then been applied to the flat-field frames used to calibrate all science frames.

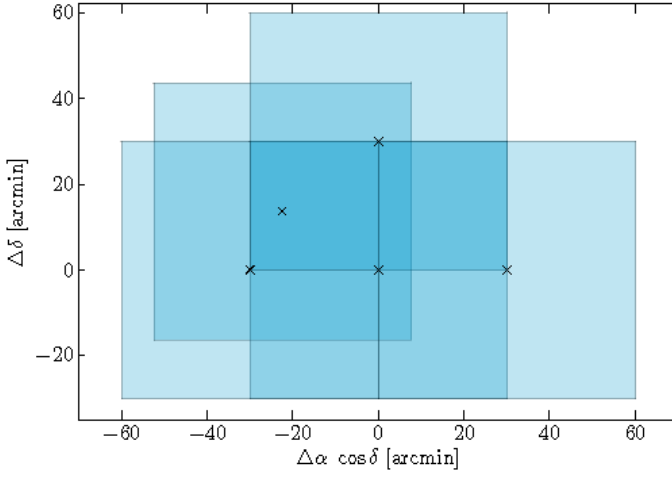


Fig. 6. Dithering pattern used for the observation of the SA107, which has been used to compute the illumination map. *Crosses* mark the five centres of the pointings, while the *rectangles* represent the OmegaCAM FoV.

In wide-field instruments, the illumination variation pattern across the large detector block can vary with time, telescope position, etc. The OmegaCAM consortium reported a dependence of the OmegaCAM illumination map on the telescope rotator angle⁵. It has been however pointed out that to achieve a photometric accuracy at the 1% level, the illumination map can be considered “stable on a timescale of at least 7 months”. Our illumination map was computed from observations taken on July 2012, 1 year after the first OmegaWING observation and 1 year before the last one. To check the stability of our illumination correction, we compared OmegaWINGS photometry with WINGS and SDSS one and found no relevant variation of the photometric zero point across our images (see Sect. 5).

3.6. Stacking of science frames

During this stage the pipeline finally operates on the science frames, using the calibration frames obtained from the previous steps. As part of this reduction stage, our pipeline computes and subtracts from the images the additive sky-background contribution. This must be done since there are stray-light components mainly due to reflections due to the segmented filters. This effect can be seen in the left panel of Fig. 7, where a V-band image obtained stacking all observations of A2415 is shown. Only bias-subtraction and flat-field correction has been applied to these images, which are then stacked together without any further processing. For the sake of clarity, only a 5000×3500 pixels region is displayed. It nearly corresponds to the upper-left quadrant of the mosaic (CCDs #82, #83, #84, #90, #91, #92, see Fig. 1) An excess of light due to light scattered by the filter support is clearly visible on the right side of the image on the left panel. In addition, in the lower half of the images there are small discontinuities. These are the footprints of the borders of individual detectors on the five stacked images. These discontinuities are likely due to a non perfect flat-field correction. It is worth noticing, however, that the image in Fig. 7 is displayed using a power-law gamma correction that strongly enhances the low-brightness details. These discontinuities are of the order of the

standard deviation of the background signal. If these discontinuities were due to small uncertainties in the flat fielding, they should have been corrected as a multiplicative component. This is not the case; in fact our sky-subtraction procedure eliminates them from the final stacks (as can be seen in the right panel of Fig. 7). This means that they are considered as additive contribution. This possible mis-interpretation would introduce a minor bias in the photometric zero-point in the regions of the mosaic corresponding to the CCDs borders. Considering their limited extension, and the fact that they are present only in a few images –the reason for this is not completely clear–, they can be ignored, as they will not affect the quality of the photometric calibration at levels higher than a few percent, that is the requirement for our scientific programme.

The presence of the additive stray-light component would not be an issue for stellar photometry, but we must correct for it since we are interested in surface photometry of extended sources. First of all, a standard calibration of the science frames is performed. Over- and pre-scan regions are trimmed from raw images, these are then bias-subtracted and flat-field corrected.

Then, the sky-background is computed assuming that it is constant for the five consecutive images belonging to the same DB. Under this assumption it can be computed with an algorithm similar to the one commonly used to remove the background from infrared observations or to correct for fringing patterns; indeed we used the ALAMBIC fringing map estimator, fully described in the ALAMBIC User Manual. Further details of the algorithms are also given by Vandame (2004).

The astrometric calibration is performed for all frames using as reference the 2MASS catalog (Skrutskie et al. 2006) or the SDSS DR8 (Aihara et al. 2011), when available. Astrometric distortions are mapped using a polynomial function of order four. The absolute accuracy –measured on the final stacked mosaic– is of the order of $0''.2$ and $0''.07$ when the calibration is based on 2MASS and SDSS, respectively.

Satellite tracks are detected using a Hough-transform algorithm to search for straight lines in raw images. These are masked and flagged as bad pixels.

All images are then warped using the astrometric solution and projected in an user-defined common grid. We defined a distortion-free grid with a constant pixel scale equal to the average OmegaCAM pixels scale, i.e. $0''.213$. The grid is centred at the target cluster centre. All warped images are finally stacked together, using the single weight maps. The output is the final stacked mosaic and the corresponding weight map. We note that since we used the same reference grid for B- and V-band images, the two output mosaics for each cluster are already aligned.

4. Photometric catalogs

4.1. Source extraction

The source extraction and measure of photometric and structural parameters has been performed using SExtractor (Bertin & Arnouts 1996). B-band photometry has been carried out with SExtractor *dual-mode*, using V-band image as reference. The catalogues extracted from B- and V-band images were then matched together using a searching radius of $2''$. In the following we list the parameters we measured. For a detailed description of the algorithm used to derive them we refer to SExtractor User Manual⁶.

⁵ http://www.eso.org/sci/facilities/paranal/instruments/omegacam/doc/OCAM_illum.pdf

⁶ <http://www.astromatic.net/software/sextractor>

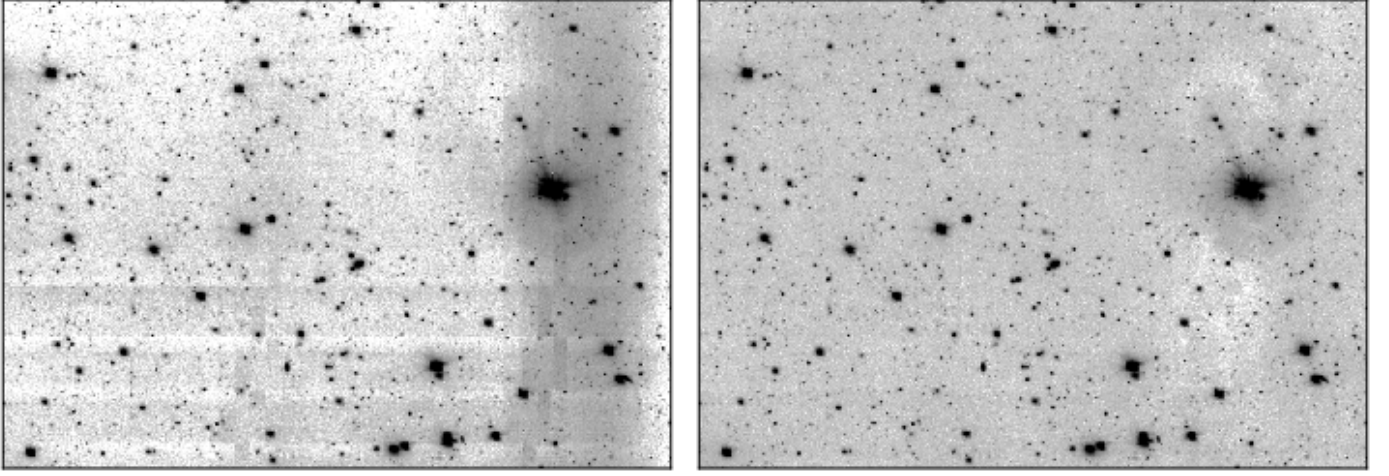


Fig. 7. Zoom of a 5000×3500 pixel region of two V-band stacked images of A2415 obtained using different procedures. The sky background has not been subtracted on the image in the *left panel*. The final product of our pipeline is shown in the *right panel*.

RA, DEC: equatorial coordinates of the barycentre of the source emission profile;
RA_PEAK, DEC_PEAK: equatorial coordinates of the source emission peak;
X, Y, X_PEAK, Y_PEAK: coordinates on the image, in pixels, of source barycentre and emission peak;
ISOAREA_IMAGE: isophotal area;
KRON_RADIUS: Kron radius;
FWHM_IMAGE: full width at half maximum;
A_IMAGE, B_IMAGE: semi-major and semi-minor axes. This has been used to compute the axial ratio b/a ;
THETA_IMAGE: position angle with respect to the North and measured counter-clockwise;
CLASS_STAR: stellarity index;
MU_MAX: surface brightness of the brightest pixel;
MAG_ISO: isophotal magnitude, defined using the detection threshold as the lowest isophote;
MAG_ISOCOR: Isophotal magnitude corrected to retrieve the fraction of flux lost by isophotal magnitudes by assuming Gaussian intensity profiles. As reported in the SExtractor user manual, “this correction works best with stars; and although it is shown to give tolerably accurate results with most disk galaxies, it fails with ellipticals because of the broader wings of their profiles”;
MAG_AUTO: Kron-like aperture magnitude. This is the most precise estimate of total magnitudes for galaxies;
MAG_APER: Aperture magnitude. We used apertures with diameter 5, 10, 15, and 20 pixels; $1''.60$, $2''.00$, and $2''.16$; 4, 10 and 20 kpc. To calculate the last three apertures we used the cluster distance listed in the WINGS database (Moretti et al. 2014).

4.2. Photometric calibration

Photometric calibration has been done using WINGS stars as local standards. We fitted the equations

$$B_{STD} - b = a_B (B - V)_{STD} + b_B \quad (2)$$

$$V_{STD} - v = a_V (B - V)_{STD} + b_V \quad (3)$$

The data have been fitted imposing the condition that the colour-term (a_B and a_V) is constant within each ESO observing

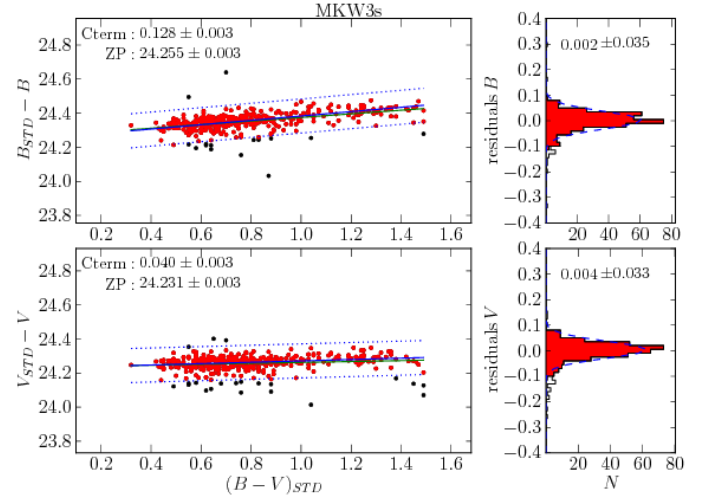


Fig. 8. An example of the photometric calibration fit obtained for all stars in common with previous WINGS photometry. In this example we used data from MKW3s observations. *Left panels* show the difference between calibrated WINGS INT photometry and instrumental OmegaCAM magnitudes as a function of the $B - V$ colour. *Upper and lower panels* show the results for B- and V-band photometry, respectively. The linear fit shown as a *blue line* was obtained clipping out outliers (*black dots*). The distribution of the residuals is well described by a gaussian function, shown in the *right panels*.

semester. As an example, Fig. 8 shows the calibration relation fitted to MKW3s data. The results for all OmegaWINGS clusters are listed in Table A.1 in the Appendix. Colour terms variations are within 0.015 mags.

4.3. Star-galaxy classification

The classification of OmegaWINGS sources was done following the method and criteria used for the original WINGS survey, as described in Varela et al. (2009). As a starting point, we classified objects on the basis of the SExtractor CLASS_STAR parameter:

stars : CLASS_STAR ≥ 0.8

galaxies : $\text{CLASS_STAR} \leq 0.2$
unknown : $0.8 < \text{CLASS_STAR} < 0.2$

We then used a set of diagnostic plots, using different combinations of SExtractor parameters to check the result and eventually correct any misclassification. As an example, in Fig. 9 the isophotal area (A^B, A^V), the central surface brightness (μ_0^B, μ_0^V) and the FWHM of sources in the A3809 field are plotted as a function of the total magnitude in both the B - and V -bands. Other parameters used for the diagnostic plots include the ellipticity and the difference between aperture photometry at 5 and 15 pixels. We visually checked all clusters looking for outliers in the diagnostic plots, i.e. sources mis-classified on the basis of the automatic classification based on CLASS_STAR. For some of them we could safely redefine the star/galaxy classification, after a careful visual inspection of their B - and V -band photometry provided a different classification; in these cases we based our classification on the results provided in the band observed under the best seeing conditions. For some of the faintest objects, with properties between those of stars and galaxies, the classification remains *unknown*. The reliability of our classification will be analysed in Sect. 5.

4.4. Data retrieval

All SExtractor measurements for all galaxies are publicly available at CDS as a single table; a unique ID is assigned to each galaxy. To this end we cross-matched the OmegaWINGS catalogue with the WINGS database (Moretti et al. 2014). For galaxies already in the WINGS database we took the WINGS-ID, while we defined a new ID for all other galaxies. A list of the columns of the catalogue is given in Table A.2. The full OmegaWINGS catalogue will be included in the next release of the WINGS database. This is planned at the end of our AAOmega spectroscopic survey. We note however that the OmegaWINGS catalogue at CDS, as any other CDS table, is already part of the VO and can therefore be easily cross-matched with the WINGS database using any VO tool, e.g. STILTS.

5. Data reduction quality checks

5.1. Astrometry

The astrometric accuracy of our catalogs has been tested against the 2MASS and SDSS DR8 -when available- stellar catalogs. By comparing the difference in the source positions, we verified that no residual distortions are present in the final mosaics. The absolute astrometric accuracy is well within the precision required for the purposes of our scientific project. For each cluster in our sample, we compared OmegaWINGS sky coordinates of all stars in the field of view with 2MASS or SDSS (depending on the catalogue used as the astrometric reference) ones. The distributions of the differences in α and δ coordinates have always negligible mean values, and typical dispersions of $0''.2$ (2MASS) and $0''.07$ (SDSS). As a further tests of the astrometric calibration accuracy, we compared the sky-coordinates of all stars in OmegaWINGS and WINGS catalogs. The dispersion of the $\Delta\alpha$ and $\Delta\delta$ distributions is a robust indicator of the accuracy of our astrometric calibration, as WINGS was calibrated independently. Results are shown in Fig. 10 and confirm that the astrometry internal calibration is accurate at a level always better

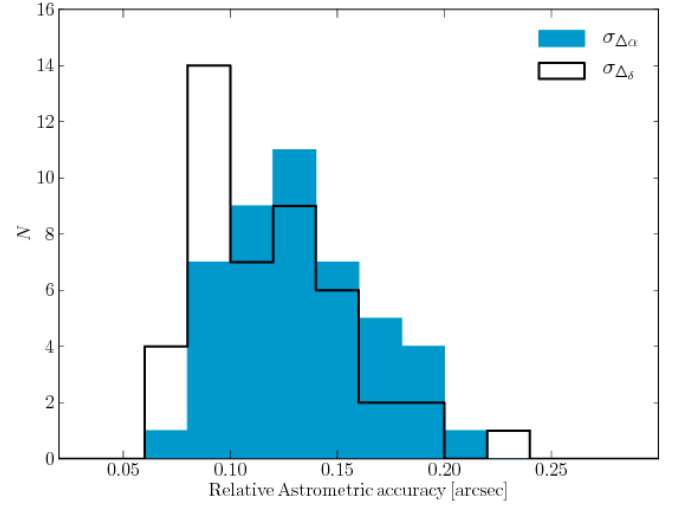


Fig. 10. Dispersion of the distributions of sky-coordinates differences between OmegaWINGS and WINGS positions of all stars in each 46 OmegaWINGS fields. Only stars brighter than $V = 20$ were used.

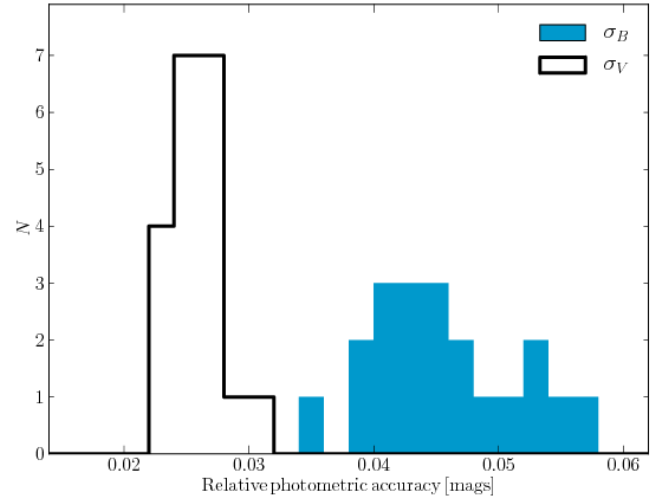


Fig. 11. Relative photometric accuracy based on a comparison with SDSS DR9. The histograms shows the dispersion of the distributions of differences between OmegaWINGS and SDSS photometry.

than $0''.2^7$. The mean values of the distributions are $\approx 0''.1$ for both right ascension and declination.

We finally note that the internal accuracies of the catalogs used as reference in this section are very close to the measured dispersions, i.e. $\sim 0''.2$, $\sim 0''.1$ and $\sim 0''.07$ when comparing OmegaWINGS astrometry with to 2MASS, WINGS and SDSS, respectively. We can therefore conclude that our astrometric calibration has an internal accuracy at the level of at least $0''.1$.

5.2. Photometry

The relative accuracy of OmegaWINGS photometry across the OmegaCAM FoV was tested by comparing OmegaWINGS pho-

⁷ The internal accuracy of WINGS astrometry is $\sim 0''.2$ (Fasano et al. 2006); values in Fig. 10 are therefore upper limits of the OmegaWINGS astrometric calibration uncertainties.

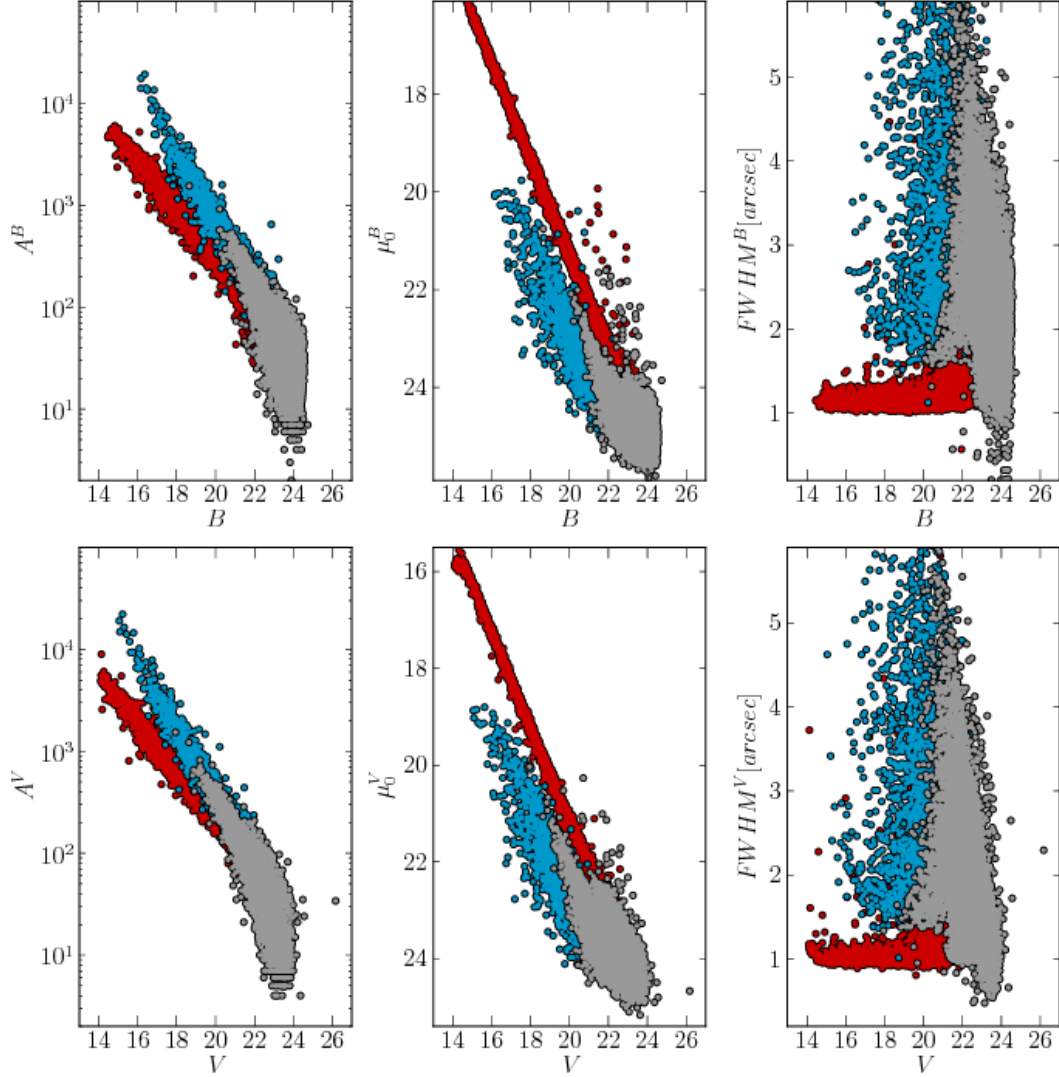


Fig. 9. Some of the plots used to classify sources in A3809, see text for details. In each panel stars are shown in red, galaxies in blue and unclassified sources in grey.

tometry with SDSS one. We adopted the linear colour equations proposed by Jordi et al. (2006) to transform SDSS *ugr* photometry into standard *BV* magnitudes. For each of the 20 OmegaWINGS field observed by SDSS, we calculated the dispersion of the differences between OmegaWINGS and (transformed) SDSS magnitudes for all stars with $B < 20$ mag and $V < 19$ mag. Results are shown in Figure 11. In the *V*-band the relative photometric accuracy is $\lesssim 0.03$ mag for all clusters. The dispersions of ΔB are 0.04–0.06 mags. The systematically higher dispersion in the *B*-band are due to non-linear colour terms in the transformations from SDSS *ugr* to *BV* photometric systems and/or a dependence of the transformations on stars metallicity/colour (Jordi et al. 2006). In Sect. 4.2 in fact we found no high-order colour term in the comparison of OmegaWINGS photometry with WINGS one. A detailed discussion of this issue is beyond the aim of this paper.

To check the spatial stability of OmegaWINGS calibration, we analysed the magnitude difference between OmegaWINGS and (transformed) SDSS photometry as a function of the position on the mosaic. As an example, the magnitude difference of all stars with $V < 19$ in Z8852 are shown in the right panel

of Fig. 12. For comparison, the same comparison when no illumination correction is applied (see Sect. 3) is shown in the left panel of Fig. 12. The maximum effect of the illumination correction, from the edge to the centre of the mosaic, is ~ 0.2 mag. We analysed the same maps as the one shown in Fig. 12 for all 20 OmegaWINGS fields with available SDSS photometry in both *B* and *V*-band and we conclude that the photometric zero point in all calibrated catalogs is constant across the whole mosaic, and that there are no residual systematic effects of neither the illumination correction nor the gain harmonisation.

Finally, the sky-subtraction procedure has been tested by performing a detailed analysis of the radial profiles of a few extended bright galaxies, and comparing the results obtained from the final OmegaCAM stacked mosaics with data from the WINGS survey. As an example, in Fig 13 the comparison of OmegaWINGS and WINGS images of a region populated by several galaxies shows that the structure of the galactic haloes is the same in the two images. This is a clear indication that the sky-subtraction procedure did remove all large-scale artefacts from the images (see Fig. 7), but it did not alter the galaxy profiles. A more quantitative analysis of this point can be derived

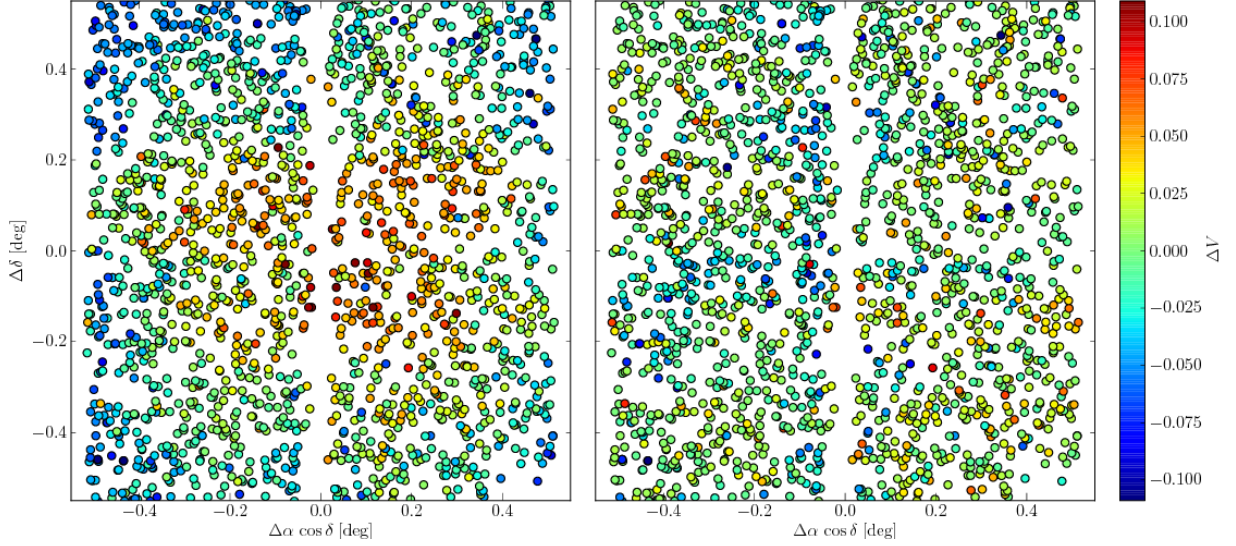


Fig. 12. Magnitude difference between OmegaWINGS and SDSS photometry –transformed onto the Johnson’s system– for stars brighter than $V = 20$ mag as a function of the position on the OmegaWINGS detector. In the *right panel* the result is obtained from the final OmegaWINGS calibrated catalog, while the photometry in the *left panel* was obtained with no illumination-correction.

from the direct comparison of radial profiles of the same galaxy obtained from OmegaWINGS and WINGS images, as the one presented in Fig. 14. The profile obtained from OmegaCAM image is in perfect agreement with the one obtained at the INT telescope, out to the detection limit, corresponding to a radius of $\sim 16''$, i.e. 75 pixels in OmegaCAM. The minor differences in the central regions are due to the fact that OmegaWINGS V -band observations of A2457 were carried out under better seeing conditions ($1''.1$) than WINGS ones ($1''.4$).

5.3. Photometric completeness

The overall OmegaWINGS photometric completeness factor was estimated by comparing the magnitude distributions (MD) of all sources in OmegaWINGS and WINGS catalogs. To perform the comparison, the WINGS distribution was re-normalised to match the total number of OmegaWINGS sources with $16 < V < 21$ mag. The MDs obtained for all 45 OmegaWINGS fields are shown in Fig. A.1 in the appendix (available only on the online version of this paper). The photometric depth depends on the seeing conditions during observations, but OmegaWINGS photometry is in general 0.5–1.0 mag shallower than WINGS one. However, when OmegaWINGS observations were carried out with seeing $\lesssim 1''.0$, OmegaWINGS is as deep as (and in some cases deeper than) WINGS (see Fig. A.1). The overall photometric depth of OmegaWINGS was estimated by stacking together all 45 MDs. Figure 15 shows that OmegaWINGS MD peaks at $V \sim 22.5$ mag and WINGS one at $V \sim 23.4$. The OmegaWINGS completeness can be estimated from as the ratio of OmegaWINGS to WINGS MDs. The 50% completeness level is reached at $V = 23.1$ mag, the 80% level at $V = 22.6$ mag (see Fig. 15). This results is based on the assumption that WINGS photometry is complete at least up to $V \sim 23$ mag. We therefore performed a further test by fitting an exponential relation to the bright tail of the histogram in Fig. 15. The completeness factor was obtained as the ratio of the observed MD to the best-fit exponential model. Following this approach, 50% and 80% completeness are found at $V = 23.3$ and 22.7 mag, respectively, confirming –within reasonable uncertainties– our previous results.

5.4. Star-galaxy classification

To check the reliability of OmegaWINGS source classification, we compared it with the WINGS one. For each cluster we divided the sources classified as galaxies in OmegaWINGS in three magnitude bins: $V < 20$ mag, $20 < V < 21$ mag, and $21 < V < 22$ mag. We then calculated how many OmegaWINGS galaxies are classified as galaxy, star, and unknown in WINGS. The histograms of these fractions are presented in Fig. 16. In all but two clusters the fraction of bright ($V < 20$ mag) OmegaWINGS galaxies classified as galaxies in WINGS are $> 97.5\%$. In more than 50% of the clusters the number of faint OmegaWINGS galaxies with unknown classification in WINGS is negligible; in all other clusters, this fraction is still smaller than 10% (see lower panel of Fig. 16). In all clusters there are no OmegaWINGS galaxies with $V < 20$ mag classified as stars in WINGS. The fraction of galaxies misclassified as stars in WINGS is negligible ($< 5\%$) also for fainter galaxies $20 < V < 22$). To summarise, we can conclude that the classification of galaxies in OmegaWINGS is highly reliable.

The other question we addressed with this analysis is about the completeness of our classification, i.e. how many galaxies are missed by our classification? Clues on this issues can be provided by studying OmegaWINGS classification of WINGS galaxies, shown in Fig. 17. In most clusters, all WINGS galaxies with $V < 20$ mag are classified as galaxies also in OmegaWINGS, just in a few clusters there are bright WINGS galaxies otherwise classified in OmegaWINGS; their fraction is however always low (5% – 10%). The number of WINGS galaxies with $21 < V < 22$ mag with unknown OmegaWINGS classification is not negligible in a significant number of clusters. Nonetheless, in $\sim 50\%$ of the clusters the number of WINGS galaxies misclassified as stars in OmegaWINGS is 5 – 15%. The reliability of the source classification is strongly dependent on seeing conditions during the observations, and in fact the clusters with the most relevant discrepancies between OmegaWINGS and WINGS classification are those where there are relevant seeing differences between the WINGS and OmegaWINGS observations.

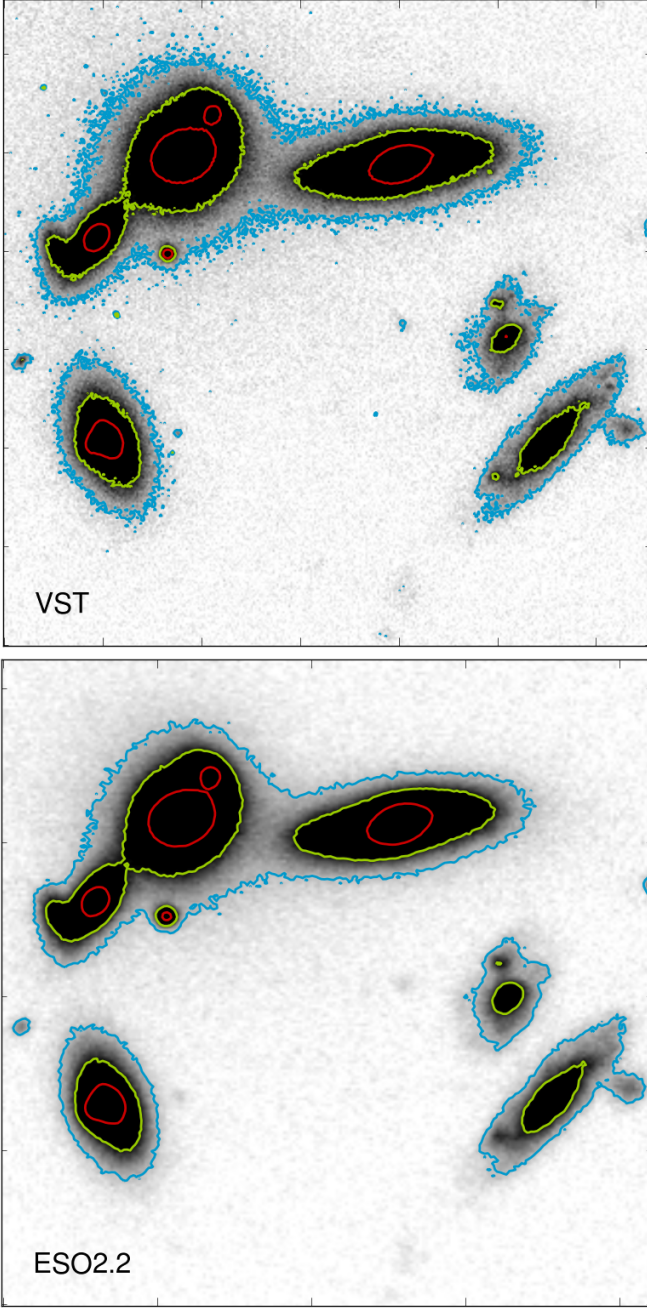


Fig. 13. Zoom on a $35'' \times 35''$ region in the V-band VST image of A151 and on the WINGS image, taken with the WFC@ESO2.2 telescope. The same contour levels have been plotted in both images. Besides the slightly lower S/N ratio of the VST image with respect to ESO@2.2 image, the shape and location of the contour is the same. This is an indication that the background subtraction did not alter the faintest structures in galaxy haloes.

To summarise, we conclude that OmegaWINGS source classification is highly reliable for all objects with $V < 20$ mag. This is the magnitude range used to select the targets for our AAOmega spectroscopic follow-up survey. At faintest magnitudes, in clusters observed under non-optimal seeing conditions, the OmegaWINGS galaxy selection is not complete, i.e. a significant number of galaxies could likely be assigned an unknown classification. On the other hand, the classification of galaxies

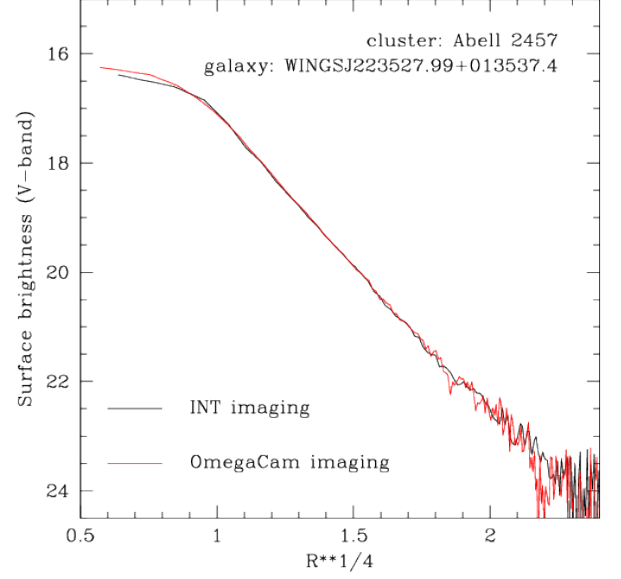


Fig. 14. Comparison of the major-axis surface brightness profile of a bright galaxy as obtained from OmegaCAM and WFC@INT images. The agreement of the two profiles demonstrates the reliability of our sky subtraction procedure.

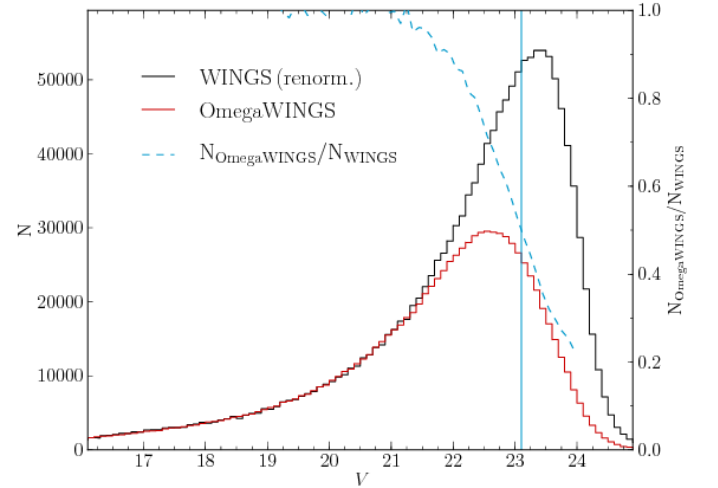


Fig. 15. V-band magnitude distribution of all objects in the OmegaWINGS and WINGS database. WINGS MD was renormalised to match the total number of sources with $16 < V < 21$ mag. The ratio of OmegaWINGS to WINGS MDs is shown as a dotted line; the corresponding scale is shown on the right-hand axis. The vertical is traced at the magnitude corresponding to a ratio of 0.5 (50% completeness level).

in OmegaWINGS is very robust, i.e. it is very unlikely that a OmegaWINGS galaxy is actually a star.

6. Summary

This paper is the first of a series presenting OmegaWINGS, the wider-field extension of the WINGS database for X-ray selected galaxy clusters at $z = 0.04-0.07$. The B - and V -band observations

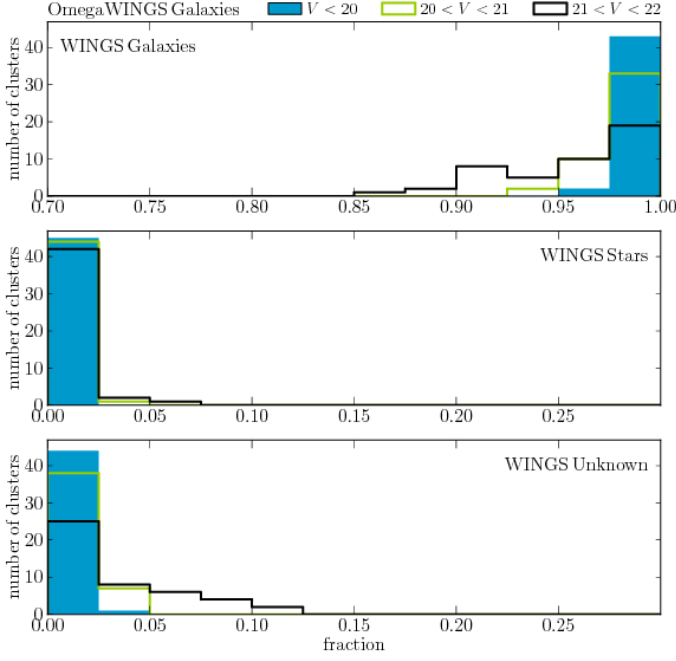


Fig. 16. Fraction of objects classified as galaxies in OmegaWINGS that have been classified as galaxies (*upper panel*), stars (*central panel*), or with unknown classification (*lower panel*) in WINGS. In each panel solid blue, green and black histograms show objects in three different magnitude bins, as indicated in the legend.

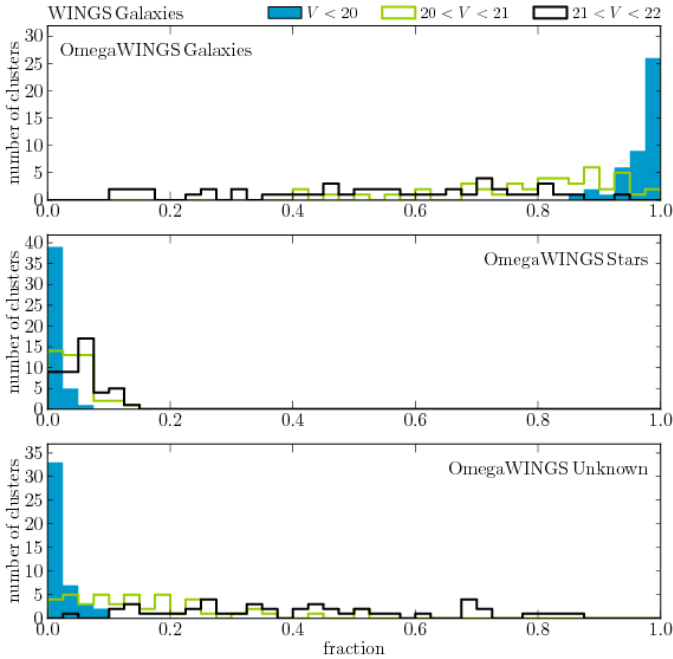


Fig. 17. Fraction of objects classified as galaxies in WINGS that have been classified as galaxies (*upper panel*), stars (*central panel*), or with unknown classification (*lower panel*) in OmegaWINGS. In each panel solid blue, green and black histograms show objects in three different magnitude bins, as indicated in the legend.

of the 46 WINGS clusters observed with OmegaCAM/VST are presented here, while the ongoing *u*-band OmegaCAM/VST and spectroscopic AAOmega/AAT follow-ups will be presented in subsequent papers.

All clusters have been observed for 25 min in each band, with a median seeing of 1'' in both *B* and *V*-band, and < 1''/3 and 1''/2 in 80% of the *B*- and *V*-band images, respectively. The data have been reduced with a modified version of the ESO-MVM ALAMBIC reduction package, developing ad hoc cross-talk, gain harmonisation and CCD control procedures. Special care has been taken for illumination correction, using purposely obtained OmegaCAM observations of standard stellar fields.

SExtractor photometric catalogues have been produced and are released with this paper at CDS. Catalogs and reduced images will also be part of the next release version of the WINGS database.

The quality of the astrometry, photometric accuracy, star-galaxy separation and sky-subtraction have been tested in various ways and show that results are generally of the same or even better quality than the previous WINGS results. The absolute astrometric accuracy is $\sim 0''.2$ and $0''.07$ when the calibration is based on 2MASS and SDSS, respectively. The photometric catalogues are 50% complete at $V = 23.1$ mag and 80% complete at $V = 22.6$ mag.

The *B*- and *V*-band OmegaCAM images have provided the AAOmega spectroscopic targets, and have been employed to identify jellyfish candidate galaxies subject to ram pressure stripping (Poggianti et al. submitted). Ongoing analysis of these images include surface brightness analysis with GASPHOT (D'Onofrio et al. 2014) and morphological classification with MORPHOT (Fasano et al. 2012). Together with the spectroscopy, taking advantage of the large OmegaCAM field of view and, consequently, of the large clustercentric radii reached, this dataset is used to study the effects of the environment on galaxy properties out to large distances from the cluster centre and for a number of studies on the dynamical status and light distribution of the clusters.

Acknowledgements. We would like to warmly thank Hervé Bouy and Benoit Vaudane for sharing their code and for the useful discussion. We acknowledge financial support from the PRIN-INAF 2010 and 2014. BV was supported by the World Premier International Research Center Initiative (WPI), MEXT, Japan and the Kakenhi Grant-in-Aid for Young Scientists (B)(26870140) from the Japan Society for the Promotion of Science (JSPS). This publication makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation. SDSS-III is managed by the Astrophysical Research Consortium for the Participating Institutions of the SDSS-III Collaboration including the University of Arizona, the Brazilian Participation Group, Brookhaven National Laboratory, Carnegie Mellon University, University of Florida, the French Participation Group, the German Participation Group, Harvard University, the Instituto de Astrofísica de Canarias, the Michigan State/Notre Dame/JINA Participation Group, Johns Hopkins University, Lawrence Berkeley National Laboratory, Max Planck Institute for Astrophysics, Max Planck Institute for Extraterrestrial Physics, New Mexico State University, New York University, Ohio State University, Pennsylvania State University, University of Portsmouth, Princeton University, the Spanish Participation Group, University of Tokyo, University of Utah, Vanderbilt University, University of Virginia, University of Washington, and Yale University.

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Appendix A: Supplementary tables and figures

Table A.1. Photometric zero points and colour terms.

cluster	a_B	b_B	a_V	b_V	P
A119	0.116 ± 0.004	24.291 ± 0.006	0.030 ± 0.004	24.291 ± 0.006	P88
A160	0.116 ± 0.004	24.405 ± 0.005	0.030 ± 0.004	24.295 ± 0.005	P88
A193	0.116 ± 0.004	24.367 ± 0.005	0.030 ± 0.004	24.313 ± 0.005	P88
A3128	0.116 ± 0.004	24.221 ± 0.004	0.030 ± 0.004	24.266 ± 0.004	P88
A3158	0.116 ± 0.004	24.312 ± 0.004	0.030 ± 0.004	24.213 ± 0.004	P88
A500	0.116 ± 0.004	24.145 ± 0.004	0.030 ± 0.004	24.226 ± 0.004	P88
A754	0.116 ± 0.004	24.320 ± 0.003	0.030 ± 0.004	24.340 ± 0.004	P88
A957x	0.116 ± 0.004	24.313 ± 0.005	0.030 ± 0.004	24.311 ± 0.005	P88
A970	0.116 ± 0.004	24.281 ± 0.004	0.030 ± 0.004	24.333 ± 0.004	P88
A1983	0.128 ± 0.003	24.297 ± 0.004	0.040 ± 0.003	24.250 ± 0.004	P89
A2382	0.128 ± 0.003	24.294 ± 0.003	0.040 ± 0.003	24.293 ± 0.004	P89
A2399	0.128 ± 0.003	24.357 ± 0.003	0.040 ± 0.003	24.267 ± 0.003	P89
A2415	0.128 ± 0.003	24.310 ± 0.003	0.040 ± 0.003	24.321 ± 0.004	P89
A2457	0.128 ± 0.003	24.316 ± 0.004	0.040 ± 0.003	24.287 ± 0.004	P89
A3556	0.128 ± 0.003	24.227 ± 0.003	0.040 ± 0.003	24.235 ± 0.003	P89
A3560	0.128 ± 0.003	24.299 ± 0.003	0.040 ± 0.003	24.217 ± 0.003	P89
A3809	0.128 ± 0.003	24.259 ± 0.003	0.040 ± 0.003	24.204 ± 0.003	P89
MKW3s	0.128 ± 0.003	24.255 ± 0.003	0.040 ± 0.003	24.231 ± 0.003	P89
A151	0.122 ± 0.003	24.316 ± 0.005	0.036 ± 0.004	24.229 ± 0.005	P90
A1631a	0.122 ± 0.003	24.377 ± 0.004	0.036 ± 0.004	24.285 ± 0.004	P90
A2593	0.122 ± 0.003	24.275 ± 0.004	0.036 ± 0.004	24.342 ± 0.004	P90
A3266	0.122 ± 0.003	24.259 ± 0.003	0.036 ± 0.004	24.249 ± 0.004	P90
A3395	0.122 ± 0.003	23.825 ± 0.003	0.036 ± 0.004	23.967 ± 0.003	P90
A3376	0.122 ± 0.003	24.233 ± 0.003	0.036 ± 0.004	24.164 ± 0.003	P90
Z8852	0.122 ± 0.003	24.310 ± 0.004	0.036 ± 0.004	24.261 ± 0.004	P90
A1069	0.133 ± 0.002	24.321 ± 0.003	0.044 ± 0.002	24.336 ± 0.003	P91
A147	0.133 ± 0.002	24.338 ± 0.004	0.044 ± 0.002	24.311 ± 0.004	P91
A168	0.133 ± 0.002	24.340 ± 0.005	0.044 ± 0.002	24.299 ± 0.005	P91
A1991	0.133 ± 0.002	24.304 ± 0.004	0.044 ± 0.002	24.283 ± 0.004	P91
A2107	0.133 ± 0.002	24.407 ± 0.003	0.044 ± 0.002	24.356 ± 0.003	P91
A2589	0.133 ± 0.002	24.326 ± 0.004	0.044 ± 0.002	24.324 ± 0.004	P91
A2657	0.133 ± 0.002	24.286 ± 0.004	0.044 ± 0.002	24.317 ± 0.004	P91
A2665	0.133 ± 0.002	24.333 ± 0.004	0.044 ± 0.002	24.295 ± 0.004	P91
A2717	0.133 ± 0.002	24.304 ± 0.005	0.044 ± 0.002	23.847 ± 0.005	P91
A2734	0.133 ± 0.002	24.343 ± 0.004	0.044 ± 0.002	24.296 ± 0.004	P91
A3528	0.133 ± 0.002	24.277 ± 0.002	0.044 ± 0.002	24.196 ± 0.002	P91
A3530	0.133 ± 0.002	24.298 ± 0.002	0.044 ± 0.002	24.231 ± 0.003	P91
A3532	0.133 ± 0.002	24.292 ± 0.002	0.044 ± 0.002	24.212 ± 0.003	P91
A3558	0.133 ± 0.002	24.253 ± 0.002	0.044 ± 0.002	24.223 ± 0.002	P91
A3667	0.133 ± 0.002	24.247 ± 0.002	0.044 ± 0.002	24.257 ± 0.002	P91
A3716	0.133 ± 0.002	24.311 ± 0.002	0.044 ± 0.002	24.265 ± 0.003	P91
A3880	0.133 ± 0.002	23.841 ± 0.004	0.044 ± 0.002	24.289 ± 0.004	P91
A4059	0.133 ± 0.002	24.286 ± 0.004	0.044 ± 0.002	24.250 ± 0.004	P91
A85	0.133 ± 0.002	24.372 ± 0.004	0.044 ± 0.002	24.315 ± 0.004	P91
IIZW108	0.133 ± 0.002	24.325 ± 0.002	0.044 ± 0.002	24.278 ± 0.002	P91

Table A.2. Description of the table available at CDS.

column	units	description
WINGS-ID		unique identifier
cluster name		name of host cluster
RA(J2000)	deg	Right Ascension of emission peak
DEC(J2000)	deg	Declination of emission peak
Area	arcsec ²	Isophotal area
KronRad	arcsec	Kron radius
FWHM	arcsec	Full width at half maximum along major axis
b/a		axial ratio
PA	deg	[-90/90] Position angle (North=0, Eastwards)
μ_B^0	mag arcsec ⁻²	<i>B</i> -band surface brightness of the emission peak
μ_V^0	mag arcsec ⁻²	<i>V</i> -band surface brightness of the emission peak
B_{ISO}	mag	<i>B</i> -band SExtractor's MAG_ISO
V_{ISO}	mag	<i>V</i> -band SExtractor's MAG_ISO
B_{ISOC}	mag	<i>B</i> -band SExtractor's MAG_ISOC
V_{ISOC}	mag	<i>V</i> -band SExtractor's MAG_ISOC
B_{AUTO}	mag	<i>B</i> -band SExtractor's MAG_AUTO
V_{AUTO}	mag	<i>V</i> -band SExtractor's MAG_AUTO
B_{2pix}	mag	<i>B</i> -band magnitude in aperture of 2 pixels
V_{2pix}	mag	<i>V</i> -band magnitude in aperture of 2 pixels
B_{5pix}	mag	<i>B</i> -band magnitude in aperture of 5 pixels
V_{5pix}	mag	<i>V</i> -band magnitude in aperture of 5 pixels
B_{10pix}	mag	<i>B</i> -band magnitude in aperture of 10 pixels
V_{10pix}	mag	<i>V</i> -band magnitude in aperture of 10 pixels
B_{5pix}	mag	<i>B</i> -band magnitude in aperture of 5 pixels
V_{5pix}	mag	<i>V</i> -band magnitude in aperture of 5 pixels
B_{10pix}	mag	<i>B</i> -band magnitude in aperture of 10 pixels
V_{10pix}	mag	<i>V</i> -band magnitude in aperture of 10 pixels
B_{4kpc}	mag	<i>B</i> -band magnitude in aperture of 4 kpc
V_{4kpc}	mag	<i>V</i> -band magnitude in aperture of 4 kpc
B_{10kpc}	mag	<i>B</i> -band magnitude in aperture of 10 kpc
V_{10kpc}	mag	<i>V</i> -band magnitude in aperture of 10 kpc
B_{20kpc}	mag	<i>B</i> -band magnitude in aperture of 20 kpc
V_{20kpc}	mag	<i>V</i> -band magnitude in aperture of 20 kpc
B_{fib1}	mag	<i>B</i> -band magnitude in aperture of 1''60
V_{fib1}	mag	<i>V</i> -band magnitude in aperture of 1''60
B_{fib2}	mag	<i>B</i> -band magnitude in aperture of 2''00
V_{fib2}	mag	<i>V</i> -band magnitude in aperture of 2''00
B_{fib3}	mag	<i>B</i> -band magnitude in aperture of 2''16
V_{fib3}	mag	<i>V</i> -band magnitude in aperture of 2''16

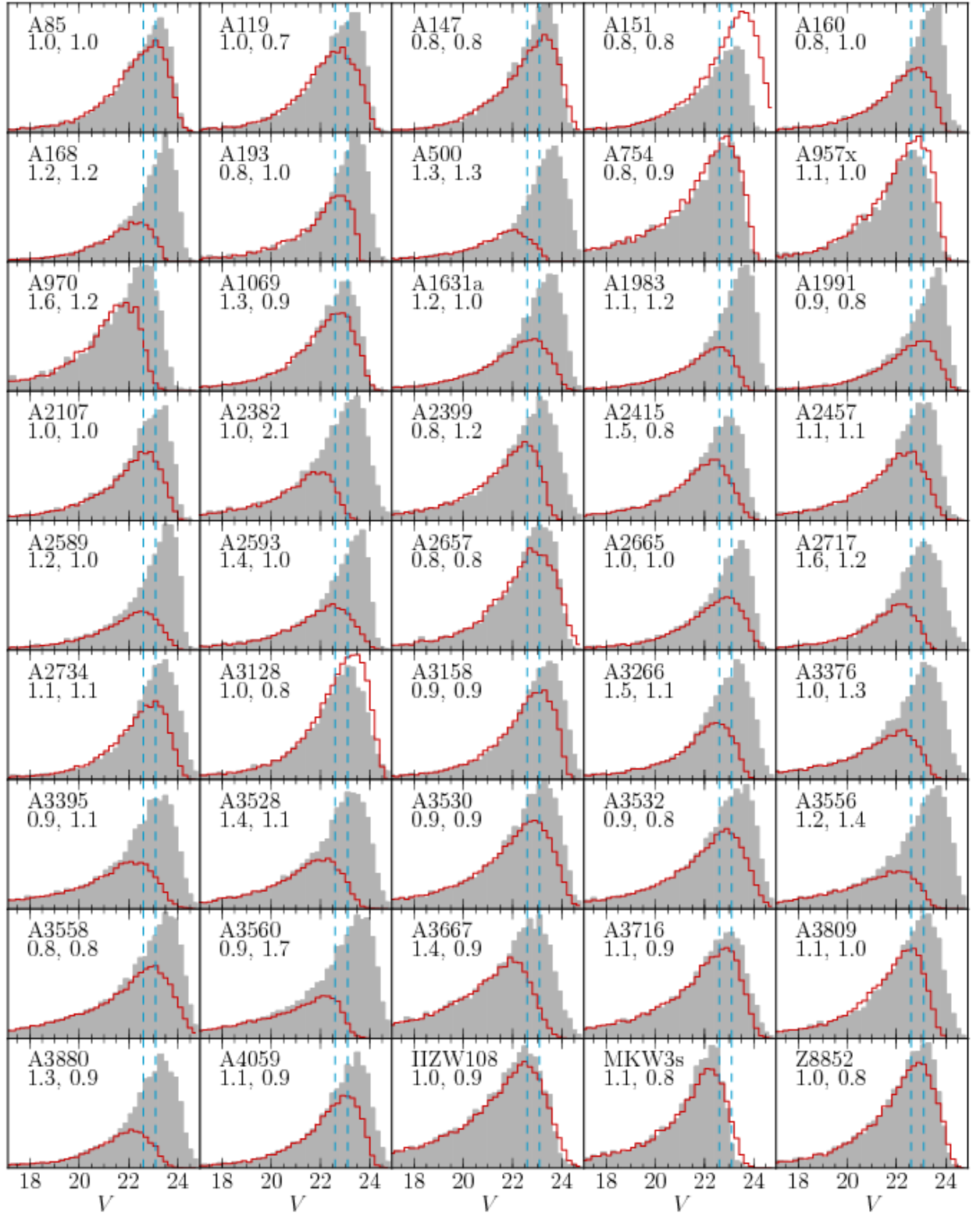


Fig. A.1. Magnitude distributions of all sources in OmegaWINGS (red histograms) and WINGS (shaded grey histograms) for all 45 OmegaWINGS fields. WINGS MDs are renormalised to match the number of bright ($16 < V < 21$ mag) objects in OmegaWINGS LFs. The vertical lines show the overall OmegaWINGS 50% and 80% completeness level (see Sect. 5.3). The label in each panel indicates the seeing in B- and V-band images, in arcseconds.